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To Dr. D. Mills  
Director of Research

**GENERATOR CONDITION MONITORS  
COMPARISON OF HEATED AND UNHEATED ION CHAMBERS**

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**ABSTRACT**

The generator condition monitor (GCM) was developed in an attempt to detect overheating inside large turbine generators. Their performance and value to operators are still subjects of discussion. As part of a broader study involving also tagging compounds, two different Environment One generator condition monitors were evaluated under field conditions at Nanticoke TGS using small resistors coated with conventional insulating paints and varnishes and controlled through the instrumentation feed-through panel. The GCM responded very rapidly to an overheating event, typically within two minutes, even for hot spots as small as 10 cm<sup>2</sup>. Similarly the aerosols produced on overheating were extremely short lived, decaying within two to three minutes after overheating was discontinued. Use of heated ion chambers was found to desensitize the GCM regardless of the nature of the overheated insulation and in some cases would altogether prevent the GCM from reaching the 50% pre-set alarm level commonly used on GCMs. Use of heated ion chambers is generally not recommended except where severe oil mist problems may exist.

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## INTRODUCTION

The detection of overheating inside a large turbine generator before it has reached catastrophic levels is notoriously difficult. The generator condition or core monitor (GCM) was developed in the 1960's in an attempt to detect such overheating on-line [1]. The GCM is essentially a smoke detector triggered by the breakdown of overheated insulation or overheated or mechanically atomized oil from the hydrogen seals. Ontario Hydro has a long standing interest in GCMs with trial tests going back to 1974. In 1980-1982 all eight Nanticoke TGS generators were retrofitted with GCMs, while the four Bruce NGS B turbogenerators came, factory-equipped, with monitors [2]. In spite of their long service history worldwide, there remains an ongoing debate on their reliability and usefulness to provide an early warning of generator insulation overheating.

The purpose of the first phase of the present study was to assess the operational performance of the GCM system at Nanticoke and particularly to perform a comparison of heated and unheated ion chambers. To allow for this assessment, the generator was fitted during routine maintenance with small painted resistors, wired through the instrumentation feed-through panel, to enable controlled overheating experiments. In the second phase of the study the collection effectiveness and the ability to locate overheating within a generator using tagging compounds will be investigated.

## GCM AND INSULATION BREAKDOWN

The breakdown of generator insulation upon overheating leads to the formation of low molecular weight volatile organic byproducts. The volatiles are released into the generator hydrogen coolant where contact with a high velocity, cool gas stream causes condensation of some of the vapors, resulting in the formation of particulate matter (ie an aerosol). Particulates are extremely short lived in a generator atmosphere, depending on aerosol diameter, but the non-condensing, low boiling volatiles are long lived, disappearing basically at the rate of hydrogen make-up to the generator. Both volatiles and particulate matter have been used as the basis for diagnostic techniques.

Much research has been carried out on the decomposition of organic insulating materials to establish both the temperature profiles and the nature of the byproducts formed [3,4]. A typical thermal breakdown curve for an insulating varnish in a hydrogen atmosphere is shown in Figure 1. Loss of weight is particularly rapid at elevated temperatures with particulation temperatures of generator insulation materials generally upwards of 250°C. Particulates must be detected when produced and they are clearly associated with incipient fault conditions.

Particulates can be readily detected by simple smoke detectors and these form the heart of the different GCMs. The devices continuously sample the hydrogen coolant and output from the GCM is monitored. The principle of the detector is based on the detection of the drift current generated between two electrodes by a gas ionized by a radioactive source. When particulate matter enters the detector, as a result of overheating or otherwise, ions become attached to the particulates and the output current drops. An alarm can be brought in, eg. at a preset drop in output. To minimize false alarms, the operation of the monitor is verified by inserting a filter in the hydrogen stream to eliminate all particulate matter and ensure return to baseline and hence proper operation. Provision is also made to take a sample of the hydrogen coolant automatically during an alarm for off-line laboratory analysis. This would confirm the nature of the alarm condition of the generator and provide an identification of the particulates collected and hopefully trace them to the origin of the overheating. GCMs are presently made by three

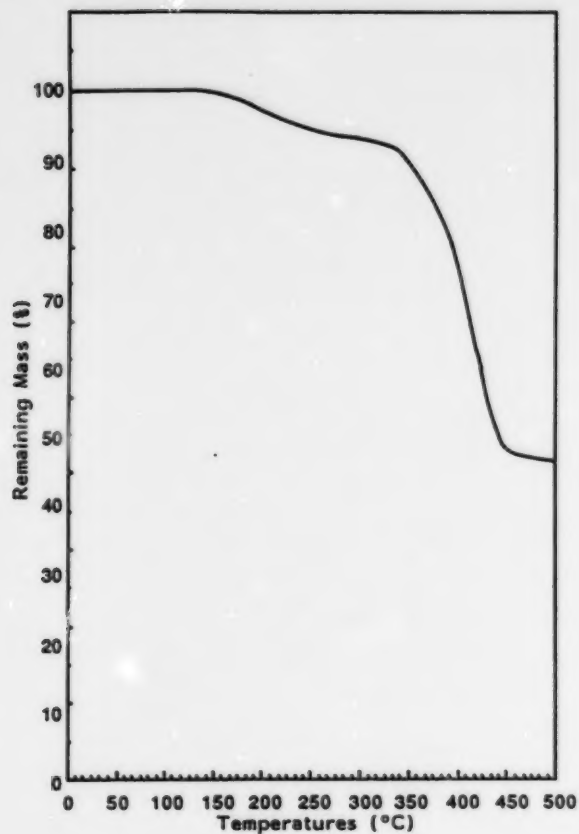


**FIGURE 1**  
**TGA PROFILE FOR INSULATING VARNISH**  
**ILLUSTRATING RAPID LOSS IN WEIGHT AROUND 400°C**

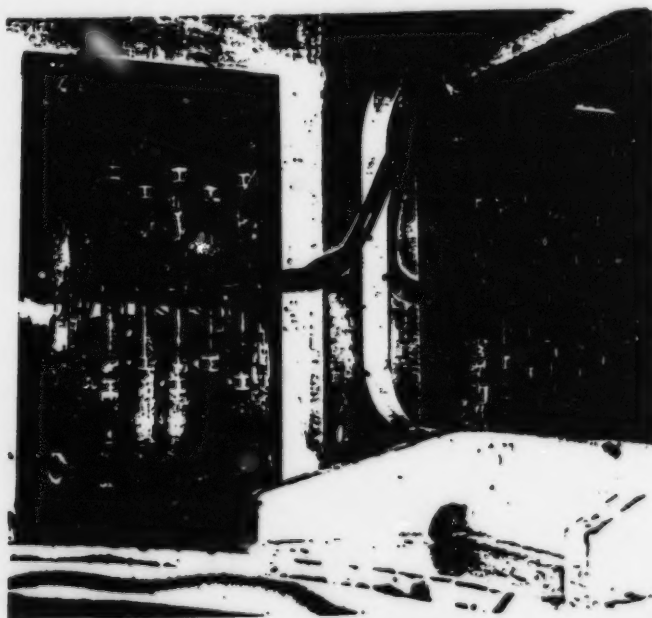


**FIGURE 2**  
**VIEW OF PAINTED RESISTORS ASSEMBLED**  
**INSIDE TURBOGENERATOR**

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manufacturers, GE and Environment One in the US and NEI Electronics in the UK. Since their introduction by GE in the 1960's the basic design was only slightly modified to eliminate oil mist problems. This is achieved by operating the ion source at higher temperatures, effectively vaporizing the aerosol [5].

The reliability of GCMs has generally been good [6-8]. The common reference to false alarms made by number of users must be placed in its proper context. The triggering of a GCM as a result of particular generator operating conditions or the presence of oil mist or other particulate matter cannot be regarded as an instrument malfunction even though it results in a nuisance alarm. Nonetheless such repeated nuisance alarms are a hindrance to effective operation of the the turbogenerator. The introduction of heated ion chambers was meant to overcome the most common cause of such alarms. It is clear, however, that improvements in the interpretation of GCM alarms are required.

Analysis of the particulates trapped on the filter to identify the overheated insulation has been attempted to assist in the location of the hot spot [9]. This is usually done by mass spectrometry alone or in combination with gas chromatography (GC) using reference insulation decomposition patterns to identify the materials involved. While overheated insulation and/or oil could be readily and accurately identified in the laboratory, all field tests have so far proven inconclusive. When known quantities of insulation were deliberately pyrolyzed inside a generator from overheated test coils, an alarm was brought in at the GCM but analysis of the aerosol trapped on the filter could not identify the material involved. The trapped material was consistently and erroneously identified as oil [10]. Theories are being developed to explain the phenomena at play, involving either the type of aerosol formed in a high velocity gas stream or the nucleation process itself. Tagging compounds with unique chemical species dispersed in coatings and varnishes were thus developed to allow for easier identification and location of the overheating event.

Periodic sampling of the hydrogen coolant gas for analysis of volatile organics has also been advocated and is practiced on a routine basis by a number of utilities including Detroit Edison and the CEGB [11,12]. The rationale behind gas analysis is that the method could be used to detect slowly developing faults long before the GCM would be triggered. This sampling can be practiced quite independently from a GCM. By and large, these volatile compounds are similar - though lighter - than those found in particulates. Within a family of chemical derivatives (eg, epoxies), these byproducts are also all very similar; correlations have nonetheless been attempted, at least under laboratory conditions [4]. Experience at Ontario Hydro (predominantly on Unit 5 at Nanticoke) and elsewhere is somewhat mixed as it has proven very difficult to identify slowly developing faults.

## EXPERIMENTAL

A thin layer of a generator coating and/or varnish material was brushed onto small ceramic 100 W power resistors and allowed to cure. A total of 24 resistors was thus prepared for field installation. The painted resistors were assembled and secured on a board as shown in Figure 2 and installed in the south side of the exciter end of the Nanticoke Unit 5 turbine generator. To further ensure the safety of the assembly, fine copper netting was used to wrap the completed assemblies and collect any debris should any of the resistors or connecting components come loose. Each resistor was connected through the instrumentation feed-through panel to allow for energizing and overheating. A thermocouple was mounted in the center of each resistor and the leads brought through the instrumentation feed-through panel to determine surface temperatures.

Two GCMs, heated and unheated, were available for the duration of the tests. In the heated GCM the gas in the ion chamber is maintained at a higher temperature, in our case at 125°C, to volatilize oil droplets. On going over to alarm, the power to the heater is turned off automatically. The heated GCM, on loan from Environment One, was installed by station staff directly in parallel with the existing (unheated) Environment One monitor. The GCMs were connected to the turbine generator by a piping run of no more than 10 m. Output from the GCMs was recorded both on chart paper and in parallel by digital voltmeters. As recommended by the manufacturer, the output was calibrated and set at 80% in the absence of any particulate matter, and decreasing towards 0% as particulates enter the ion chamber. The alarm level was set at 50% as done elsewhere in the station.

Analysis of specific volatiles formed by low temperature generator insulation breakdown was also undertaken by specialized gas chromatographic techniques using direct measurement as well as absorption on charcoal filters. The solid adsorbent was placed inside the GCM filter holders in lieu of the material normally used for volatile sampling. The adsorbent works by reacting with aldehydes in the surrounding gas to form a stable complex which remains bound to the solid. This complex was later removed in the laboratory by solvent extraction and quantified by gas chromatography.

## RESULTS AND DISCUSSION

### RESISTOR TESTS

GCM alarms could be repeatedly triggered by setting off the painted resistors. Adequate surface temperatures were obtained when the resistors were energized to produce insulation breakdown in spite of effective hydrogen cooling and the limited current carrying capabilities of the resistor leads at the feed through panel. Temperature rise times obtained with the arrangement of Figure 2 could be varied over a broad range with a maximum of better than 100°C/min. To standardize on temperature profiles and hence GCM output, efforts were made to achieve a final temperature of about 400°C in approximately 2 to 4 minutes. Care was taken to obtain a steady GCM response before undertaking any resistor tests.

It was found that GCM response followed application of current very swiftly, generally within one to two minutes. A typical GCM chart and corresponding resistor temperatures are given in Figure 3. It can be seen that the GCM experiences a very fast decrease in output and, as would be expected, a slow return to baseline as the particulation activity of the paint ceased. On later inspection of the generator, it was established that the paint had been thoroughly carbonized. Similarly, output was found to be restored equally fast when current to the resistor was discontinued, again within approximately two minutes. These features clearly illustrate both the short travel time of the hydrogen path to the GCM and the rapid decay of particulates within the generator. This decay is typical of aerosol particulates, controlled by the diameter of the particulates and their rate of adsorption to the walls.

The heated and unheated GCMs displayed a consistent but different behavior. As pictured in Figure 4, the output from the heated ion chamber lagged significantly behind (ie. maintained a higher output) than the unheated one, in fact bringing in alarms at substantially longer times. In some cases no alarm level was reached by the hot chamber as discussed more extensively later. An alarm condition is defined (arbitrarily) as the moment the detector output falls below 50%. By construction, however, the logic of hot ion chamber operation is such that once an alarm condition is registered the power to the heater is shut off and output from both monitors is very similar, differing only by their calibration at different ion chamber temperatures, as illustrated in Figure 4.

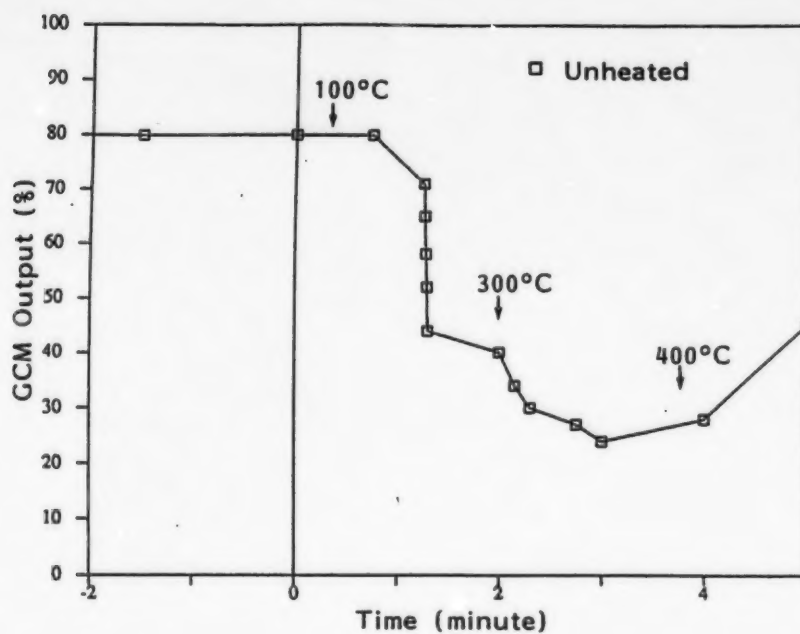


FIGURE 3a

GCM OUTPUT AND CORRESPONDING SURFACE TEMPERATURES  
FOR OVERHEATED PAINTED RESISTORS

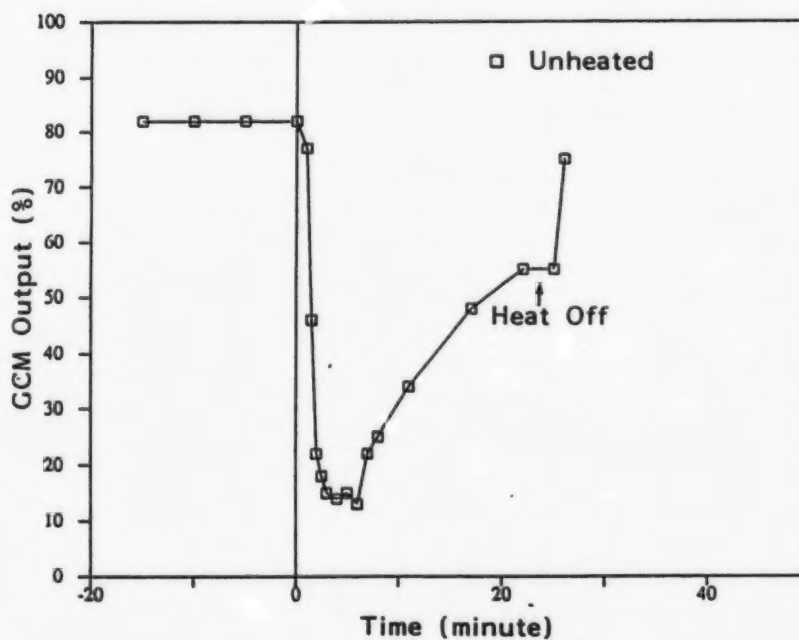


FIGURE 3b

GCM OUTPUT FOR OVERHEATED RESISTOR  
ILLUSTRATING DECAY OF PARTICULATES

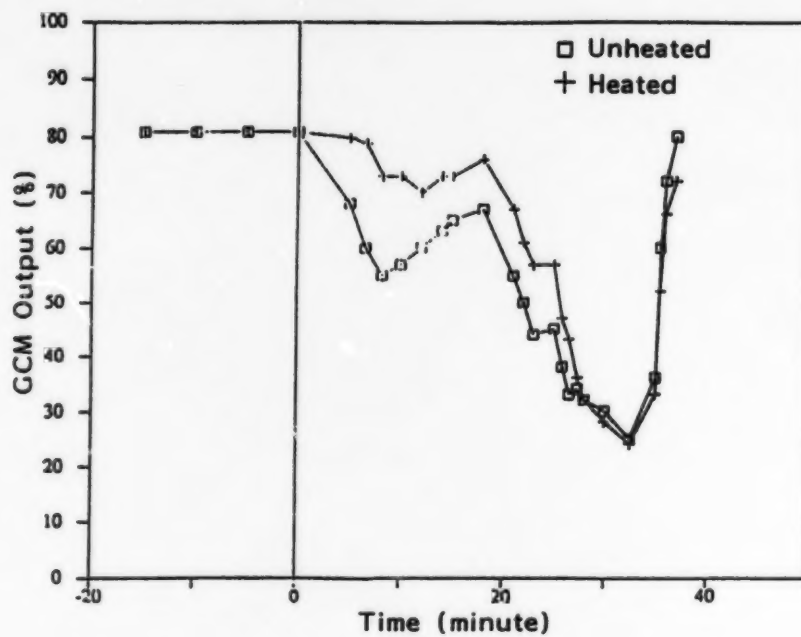


FIGURE 4

GCM OUTPUT COMPARING UNHEATED (□) AND  
HEATED (+) IOU CHAMBERS

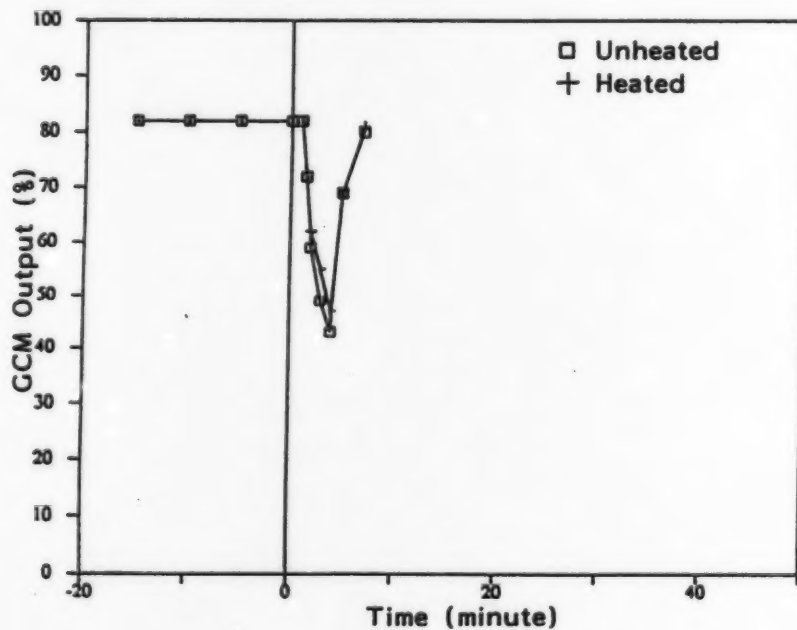


FIGURE 5

GCM OUTPUT FOR PREVIOUSLY OVERHEATED RESISTOR

These observations on heated and unheated ion chambers are presumably quite general and were recorded for both insulating paints and varnishes. As indicated above, output would go through a minimum and then be slowly restored as production of particulates ceased, even at constant resistor temperature. This is shown even more dramatically in Figure 5 where a previously overheated resistor was exposed to a second round of overheating, illustrating the much reduced particulation activity that was detected. This has clear implications for the long term reliability and usefulness of the monitor. Once exposed to a certain temperature insulation will only produce a limited amount of particulates on re-exposure and in fact higher temperatures are required to obtain strong GCM output. Similarly it is clear that once carbonized (as was the case here with the small resistors) the same area will no longer respond to overheating. This characteristic particulation feature may account for reported failures where sustained GCM alarms were received weeks before the failures but at the time of failure there was no GCM activity.

GCM output is clearly dependent on a great many variables including the temperature, rate of temperature rise and area of the hot spot, nature of the coating, hydrogen flow characteristics, etc. Experiments were carried out to gain a better understanding of these parameters with the results shown in Figures 6 to 8. The effect of the material under study on particulation activity and on GCM activity can be seen in Figure 6. The generator varnish exhibited considerably less particulation activity than a paint, as characterized by the area under the GCM curve. This may not reflect more than the differences in viscosity of the two materials and ultimately differences in applied thicknesses and/or total mass deposited on the resistor. An experimental paint with micro encapsulated oil droplets exhibited the broadest curve, possibly for the same reasons. It should be noted in particular that the response of the two monitors, in this instance, is very nearly identical despite a high oil content of this sample. These differences in GCM activity are not immediately obvious and should certainly be borne in mind when attempting to interpret GCM output curves.

The performance achieved with coatings of different surface area is shown in Figure 7 for resistors bearing coatings of between 12 and 90 cm<sup>2</sup>. As would be expected the smaller area coatings demonstrated much reduced particulation activity as measured by the area under the curve, with a substantially lower area under the response curve. It should be noted, however, that the order of response, at least as expressed by the largest reduction in GCM output, did not follow directly the reduction in area. This could possibly be due to a complex interplay of coating thickness and rate of heat application to the resistor, beyond differences in particulation characteristics. Under optimum conditions, as met with the smaller coating, it can be seen that the GCM is potentially an extremely sensitive device with a lower detection limit well below the 12 cm<sup>2</sup> of the sample pictured here. The results obtained with the intermediate coating of 30 cm<sup>2</sup> are no less interesting in that they magnify the differences between hot and cold ion chambers. Because of a very modest rate of particulation observed here, the hot chamber lags visibly behind the cold one and, exceptionally, fails to reach the alarm level. In the case of the unheated chamber, output falls only slightly below 50%, and the signal intensity is slowly restored thereafter. There is little doubt that similar situations could be encountered in the field, leading to a minimizing of potentially serious conditions by not bringing the event to an alarm level.

The drastic effects of heating rate are clearly illustrated in Figure 8 featuring two otherwise identical resistors. Here again the slower rate of temperature rise amplifies the difference between hot and cold ion chambers, until the alarm condition is reached at which point the heater of the hot ion chamber is turned off. It is equally informative to note that the resistor heated at the slower rate apparently displayed a much increased particulation, as gained from the areas of the peaks. Since all overheated

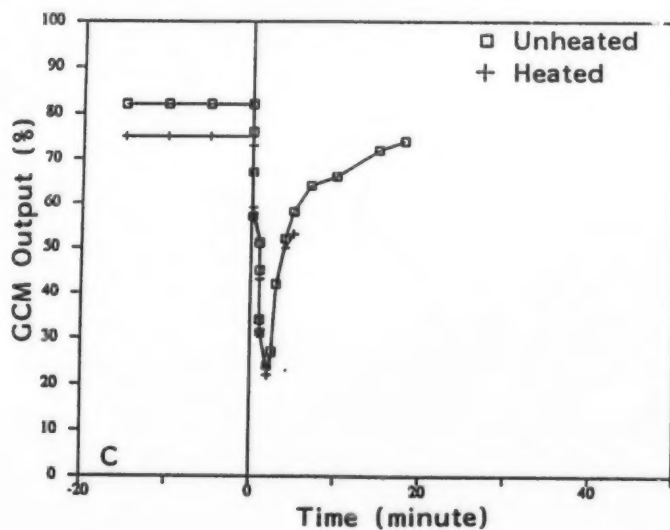
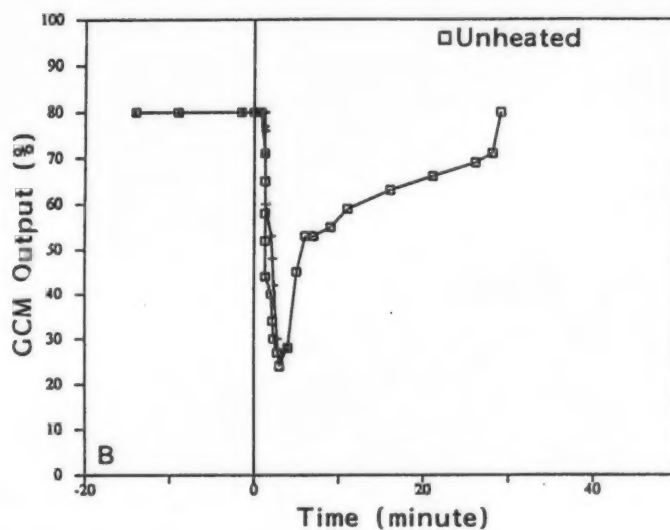
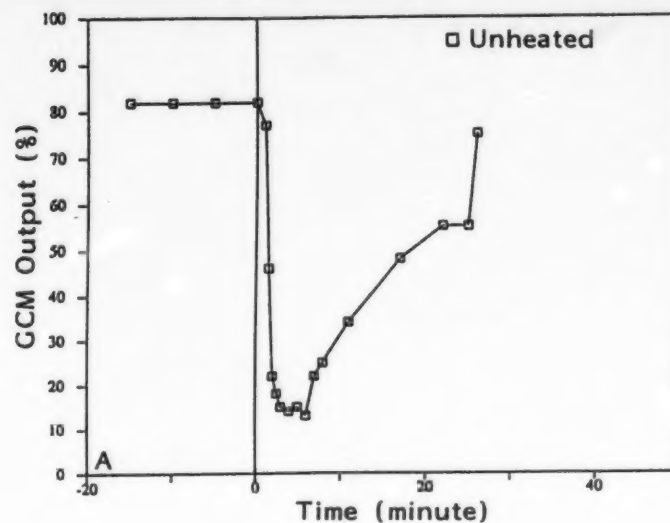


FIGURE 6  
GCM OUTPUTS FOR RESISTORS COATED WITH AN OIL  
LOADED COATING (A), EPOXY PAINT (B) AND VARNISH (C)

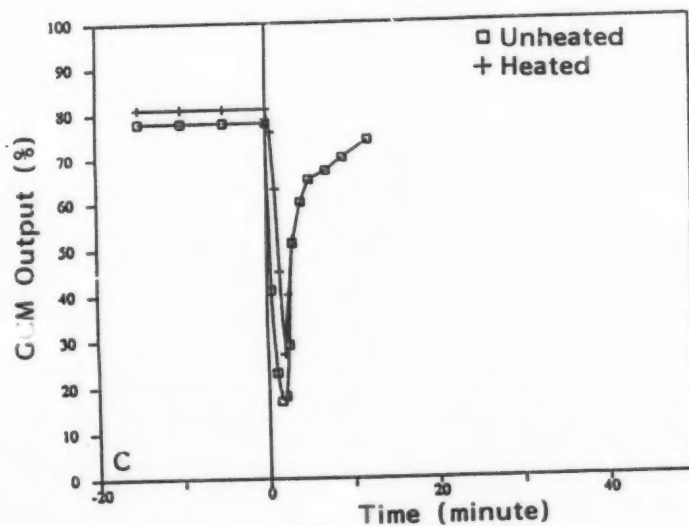
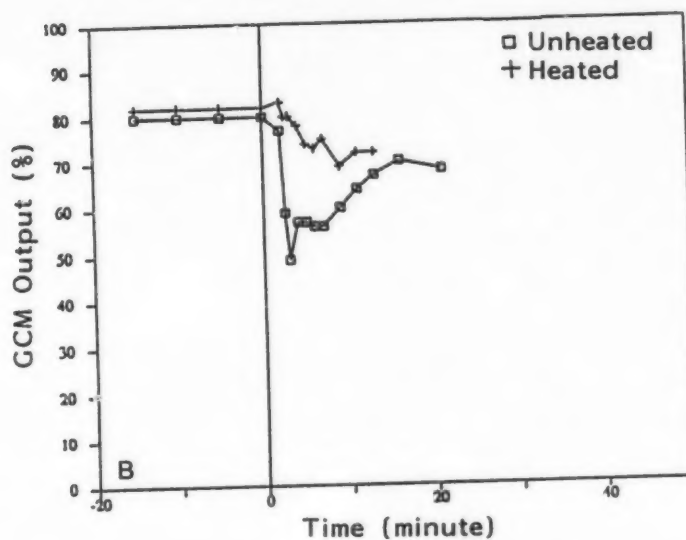
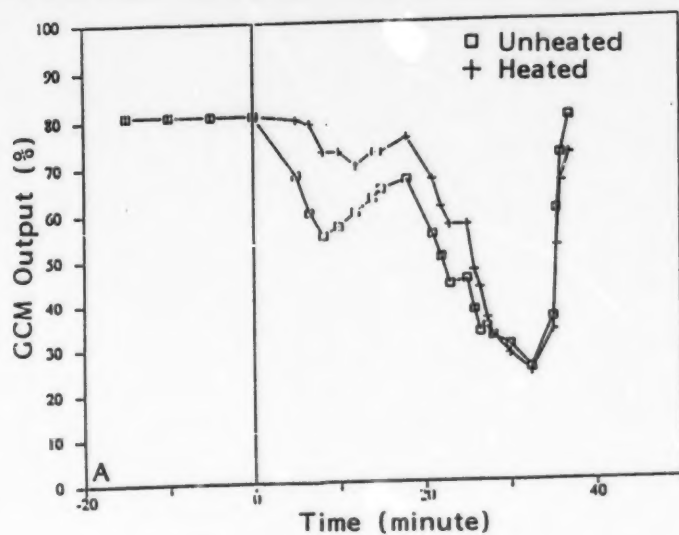


FIGURE 7  
GCM OUTPUTS FOR RESISTORS OF VARYING SIZES,  
A(90cm<sup>2</sup>), B(30cm<sup>2</sup>) AND C(12cm<sup>2</sup>)

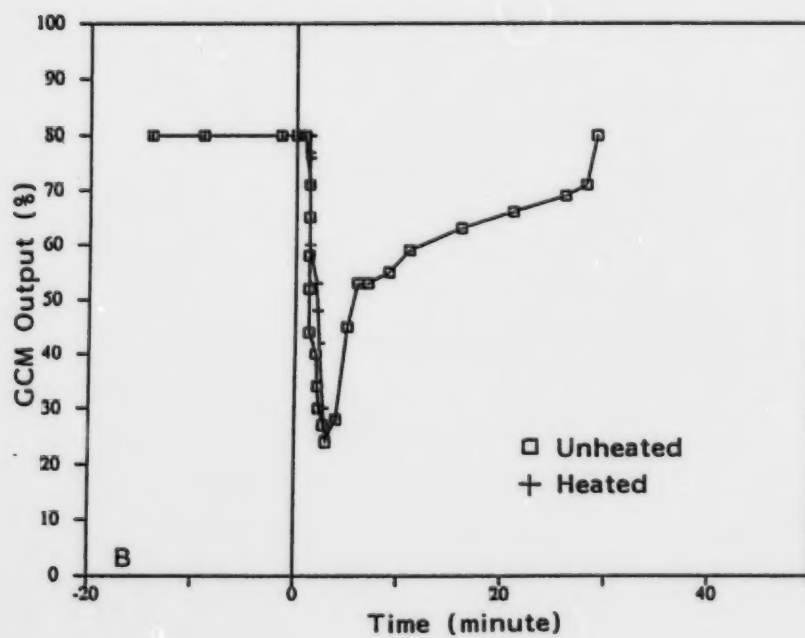
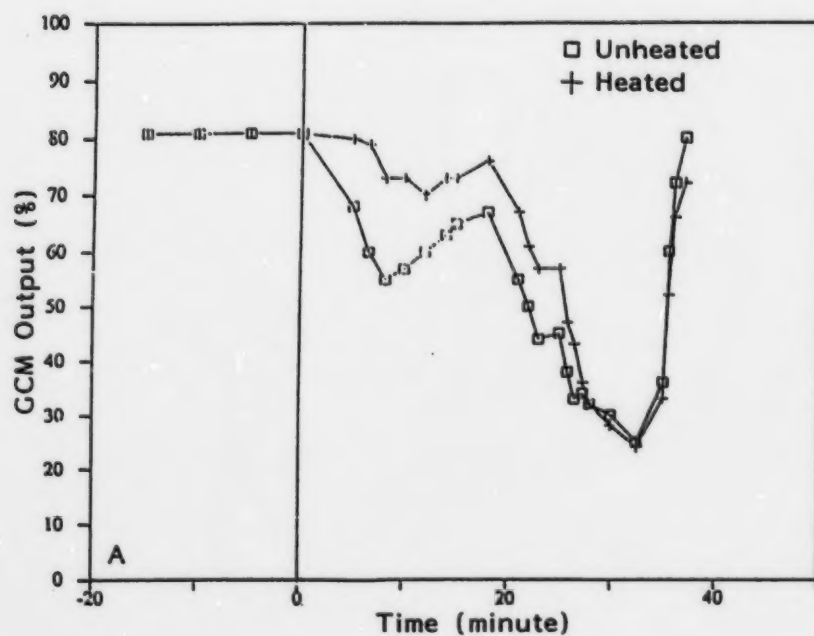


FIGURE 8  
GCM OUTPUTS FOR DIFFERENT HEATING RATES,  
A(20°C/min) AND B(150°C/min)

resistors were later found fully spent and carbonized, this difference in the production of particulates is somewhat unexpected. Unfortunately this characteristic further lessens the information that can be gathered from a GCM profile as presently operated. Clearly improvements in GCM operation and value to operation staff can be achieved by going beyond a simple monitoring with a set alarm level, notably in dealing with unusual situations and nuisance alarms. The system could be re-engineered to provide additional information (eg, trending and area under curves) via micro-processor analysis.

### **MACHINE INSULATION**

The results of Figure 9 represent GCM responses obtained by maneuvering the generator. It was well known, as reported extensively elsewhere [2], that Unit 5 had experienced an inordinate amount of GCM alarms. This was generally attributed to the extensive back of core burning, evidence of which was seen during maintenance inspections. Correlation with generator operating conditions led to fairly reliable predictions of conditions likely to bring in alarms. Accordingly, an on-line test was requested to examine the performance of the monitors under these fully realistic conditions.

A number of different operating conditions was required to bring about the desired behavior. An increase in generator power from 400 to 450 MW did not yield the desired alarm. However, a subsequent decrease in reactive power combined with an increase in real power gave the results of Figure 9. The data illustrate the complex GCM responses that can be expected from an operating, overheating generator and the substantial differences between heated and unheated chambers. In particular it can be seen that, as recorded with the resistors, a considerable lag is experienced by the heated chamber, in this case alarm conditions being registered nearly 10 minutes after the alarm raised by the cold ion chamber. Moreover the monitor response is highly variable, presumably as a result of highly variable particulate production induced by a range of generator operating conditions.

Repeated production of GCM alarm conditions was extremely difficult to achieve in a second attempt at generator maneuvering to produce a different kind of alarm. While this proved somewhat frustrating, the GCM profiles again highlighted the large reduction in sensitivity of the heated GCM. As observed earlier, the largest differences were found when particulate production and hence GCM responses were minimal. As found on a previous occasion, the heated ion chamber never went into alarm during this entire run.

### **HYDROGEN GAS STREAM ANALYSIS**

The cooling gas stream was also sampled using both aldehyde specific solid adsorbents and a portable gas chromatograph. Unlike conventional gas sampling, the aim here was to detect low temperature breakdown byproducts. Related work on the development of an insulation breakdown detector had indicated the presence of carbon monoxide, aldehydes and ketones at very low insulation temperatures [13]. If successful this approach could represent a valuable route to detect the early breakdown stages in a generator, but its efficacy in the reducing atmosphere of a hydrogen cooled machine was unclear.

The results of the analyses carried out during the Nanticoke tests are shown in Table I. The hydrogen samples were taken during overheating of painted resistors, real generator GCM alarms (ie maneuvering), and included background samples, a laboratory standard and blanks. While the aldehyde concentration measurements taken during the overheating of the test resistors were slightly higher than

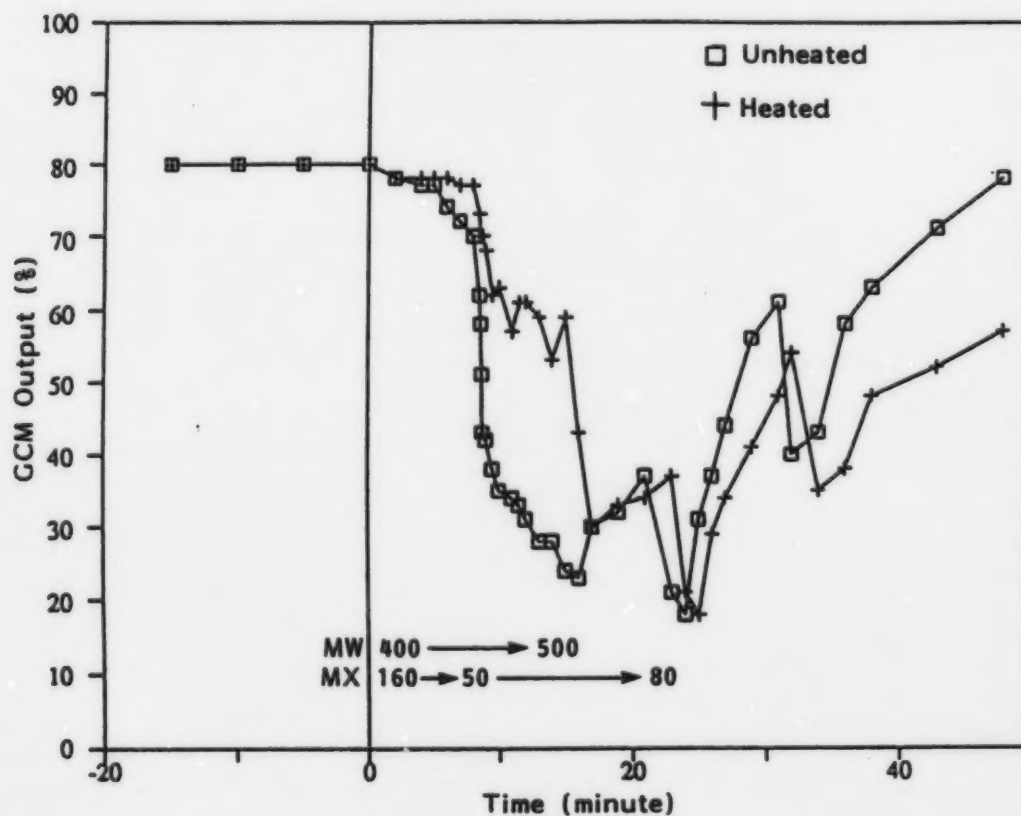


FIGURE 9  
 GCM OUTPUT AS A FUNCTION OF GENERATOR  
 MANEUVERING (MX, MW)

the background measurements, the two measurements taken during actual generator GCM alarms (induced by maneuvering) were not significantly different from the background or blank measurements. In parallel with the above off-line measurements, a sample of the hydrogen cooling gas was also taken and analyzed on site using a Photovac 10S-50 portable gas chromatograph equipped with a photoionization detector. The gas chromatograms showed no difference between background samples and samples taken during resistor overheating. The results apparently confirm the early suspicions that, despite the short time span, ketones and aldehydes are not chemically stable in the reducing hydrogen atmosphere.

**TABLE I**  
**ALDEHYDE ADSORBENT RESULTS**

| Sample # | Relative Concentration | Sample Description          |
|----------|------------------------|-----------------------------|
| 1.       | 14.86                  | Epoxy Paint Heated to 175°C |
| 2.       | 16.62                  | Epoxy Paint Heated to 400°C |
| 3.       | 14.86                  | Hydrogen Gas Background     |
| 4.       | 16.31                  | Varnish Heated to 175°C     |
| 5.       | 17.87                  | Varnish Heated to 400°C     |
| 6.       | 11.08                  | Hydrogen Gas Background     |
| 7.       | 13.00                  | Acetaldehyde Standard.      |
| 8.       | 15.35                  | GCM at 20% Output           |
| 9.       | 11.30                  | GCM at 40% Output           |
| 10.      | 11.30                  | Blank                       |
| 11.      | 11.30                  | Blank                       |

## CONCLUSIONS

Heated and unheated ion chambers exhibit a considerable difference in response to overheated insulation under actual field conditions. While specifically designed to overcome nuisance alarms created by oil mists, it was found that the sensitivity of the heated ion chamber was reduced with all overheated insulation. Fast developing faults will generally be caught as rapidly by either but response of the heated chamber to a slow increase of particulate in the gas stream may never reach an alarm stage, as found in these tests. Except under special circumstances, it is quite clear that the unheated ion chamber is by far the superior choice.

GCMs respond very rapidly to overheating events. In spite of dilution in a large mass of hydrogen, alarm conditions could be generated within two minutes from application of over-temperatures to resistors placed at the exciter end of the generator. Similarly the life of particulates is extremely short within the generator, output of the GCM returning to normal within two to three minutes after current was removed from the resistors. Under sustained overheating conditions the output will slowly return to baseline as production effectively ends. On reheating of the same insulation, very little GCM activity is detected and this phenomenon could well account for steady GCM output at the time of a generator fault.

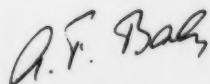
GCM response to overheating insulation is very complex. Some of the factors identified include the rate of temperature rise, type, mass and area of the coating. The detector can be very sensitive to overheated insulation and it is believed that under ideal conditions (eg. fast rate of rise) an area as small as a few cm<sup>2</sup> could bring in a (short duration) alarm.

Aldehydes and ketones could not be detected in the hydrogen stream as indicators of early, low temperature decomposition of insulating materials.

Additional tests are planned during phase 2 of the program, using the same approach, to evaluate tagging compounds and their usefulness in locating overheating inside a turbogenerator.

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